6. NATURAL GAS COMBINED CYCLE (NGCC)

6.1 MARKET-BASED NGCC

6.1.1 Introduction

Two market-based designs are presented and are based on the use of a natural gas-fired combustion turbine (CT) coupled with a heat recovery steam generator (HRSG) to generate steam for a steam turbine generator. The plant configuration reflects current information and design preferences, the availability of newer combustion and steam turbines, and the relative latitude of a greenfield site.

The first rendition of CT/HRSG technology is based on selection of a gas turbine exemplified by the Westinghouse 501G machine. This particular machine provides values of power output, airflow, and exhaust gas temperature that effectively couple with a HRSG to generate steam for the companion steam cycle plant to produce a total net output of 326 MWe, at an efficiency of 50.6 percent (HHV). For this study, a single gas turbine is used in conjunction with one 1650 psig/1000°F/1000°F steam turbine.

The second rendition of a CT/HRSG technology is based on selection of a gas turbine represented by the General Electric "H" machine. This machine also provides values of power output, airflow, and compressor pressure ratio that provide a good match with the HRSG to generate steam for the companion steam cycle plant to produce a total net output of 395 MWe at an efficiency of 53.4 percent HHV. One gas turbine is combined with an 1800 psig/1050°F/1050°F steam turbine.

6.1.2 Heat and Mass Balance

The first market-based plant described in this section is based on use of one Westinghouse 501G gas turbine generator coupled with a triple-pressure HRSG supplying steam to one steam turbine generator. The second market-based plant is based on the use of one General Electric "H" gas turbine generator coupled with a triple-pressure HRSG supplying steam to one steam turbine generator. The resulting power plants utilize a combined cycle for conversion of thermal energy to electric power.

Overall performance for the plants, including Brayton and Rankine cycles, is summarized in Table 6.1-1 and Table 6.1-2, which include auxiliary power requirements. Table 6.1-1 summarizes the plant based on the Westinghouse gas turbine, and Table 6.1-2 summarizes the plant based on the General Electric turbine. An open Brayton cycle using air and combustion products as working fluid is used in conjunction with the conventional subcritical steam Rankine cycle. The two cycles are coupled by generation of steam in the HRSG, and by feedwater heating in the HRSG. The overall air and steam power cycles are shown schematically in the 100 percent load Heat and Mass Balance diagrams, Figure 6.1-1 and Figure 6.1-2.

The inlet air for both plants is compressed in a single spool compressor to the design basis discharge pressure, and then passes directly on to the burner assembly. The hot combustion gases exit the burners and pass to the inlet of the turbine section of the machine, where they enter and expand through the turbine to produce power to drive the compressor and electric generator. The turbine exhaust gases are conveyed through a HRSG to recover the large quantities of thermal energy that remain. The HRSG exhausts to the plant stack.

The W501G machine uses steam to provide cooling for transition ducts between the burner assembly and the turbine inlet. In this study, the steam used for cooling is obtained by removing the steam from the HP steam drum in the HRSG, adding approximately 85°F of superheat in the superheat coil (to assure that the steam remains dry), and then throttling the steam to the appropriate pressure (590 psig). The steam is heated in the transitions to above 1100°F, and then mixed with hot reheat steam leaving the HRSG. The steam conditions were selected to match tentative generic requirements established by the gas turbine manufacturer for the steam used to cool the transitions.

The “H” turbine utilizes cold reheat from the steam turbine for cooling the stationary and rotating parts of the turbine, mainly the first- and second-stage stationary nozzle and buckets plus the stage one shroud. Cold reheat is routed to the turbine where it is heated to 1050°F and then mixed with the hot reheat steam leaving the HRSG.

Table 6.1-1
PLANT PERFORMANCE SUMMARY - 100 PERCENT LOAD
WESTINGHOUSE 501G

(Loads are presented for one gas turbine and one steam turbine)

STEAM CYCLE	
Throttle Pressure, psig	1,650
Throttle Temperature, °F	1,000
Reheat Outlet Temperature, °F	1,000
POWER SUMMARY (Gross Power at Generator Terminals, kWe)	
Gas Turbine	225,090
Steam Turbine	108,881
Total	333,971
AUXILIARY LOAD SUMMARY, kWe	
Fuel Gas Booster Compressor (Note 1)	1,600
Condensate Pumps (Note 2)	305
HP Feed Pump (Note 3)	1,430
Miscellaneous Balance of Plant (Note 4)	900
Gas Turbine Auxiliaries	400
Steam Turbine Auxiliaries	150
Circulating Water Pumps	1,190
Cooling Tower Fans	1,100
Transformer Loss	755
TOTAL AUXILIARIES, kWe	7,830
Net Power, kWe	326,141
Net Efficiency, % HHV	50.6
Net Heat Rate, Btu/kWh (HHV)	6,743
CONDENSER COOLING DUTY, 10^6 Btu/h	680
CONSUMABLES	
Natural Gas, lb/h @ 21,837 Btu/lb, HHV	100,700

Note 1 - Natural gas pressure boosted from 300 psig to 625 psig

Note 2 - Includes LP feedwater

Note 3 - Includes IP feedwater

Note 4 - Includes plant control systems, lighting, HVAC, etc.

Table 6.1-2
PLANT PERFORMANCE SUMMARY - 100 PERCENT LOAD
GENERAL ELECTRIC "H"

(Loads are presented for one gas turbine and one steam turbine)

STEAM CYCLE	
Throttle Pressure, psig	1,800
Throttle Temperature, °F	1,050
Reheat Outlet Temperature, °F	1,050
POWER SUMMARY (Gross Power at Generator Terminals, kWe)	
Gas Turbine	275,800
Steam Turbine	127,537
Total	403,337
AUXILIARY LOAD SUMMARY, kWe	
Fuel Gas Booster Compressor (Note 1)	1,680
Condensate Pumps (Note 2)	120
HP Feed Pump (Note 3)	1,630
Miscellaneous Balance of Plant (Note 4)	900
Gas Turbine Auxiliaries	400
Steam Turbine Auxiliaries	150
Circulating Water Pumps	1,240
Cooling Tower Fans	700
Transformer Loss	1,370
TOTAL AUXILIARIES, kWe	8,310
Net Power, kWe	395,027
Net Efficiency, % HHV	53.4
Net Heat Rate, Btu/kWh (HHV)	6,396
CONDENSER COOLING DUTY, 10^6 Btu/h	830
CONSUMABLES	
Natural Gas, lb/h @ 21,837 Btu/lb, HHV	115,700

Note 1 - Natural gas pressure boosted from 300 psig to 625 psig

Note 2 - Includes LP feedwater

Note 3 - Includes IP feedwater

Note 4 - Includes plant control systems, lighting, HVAC, etc.

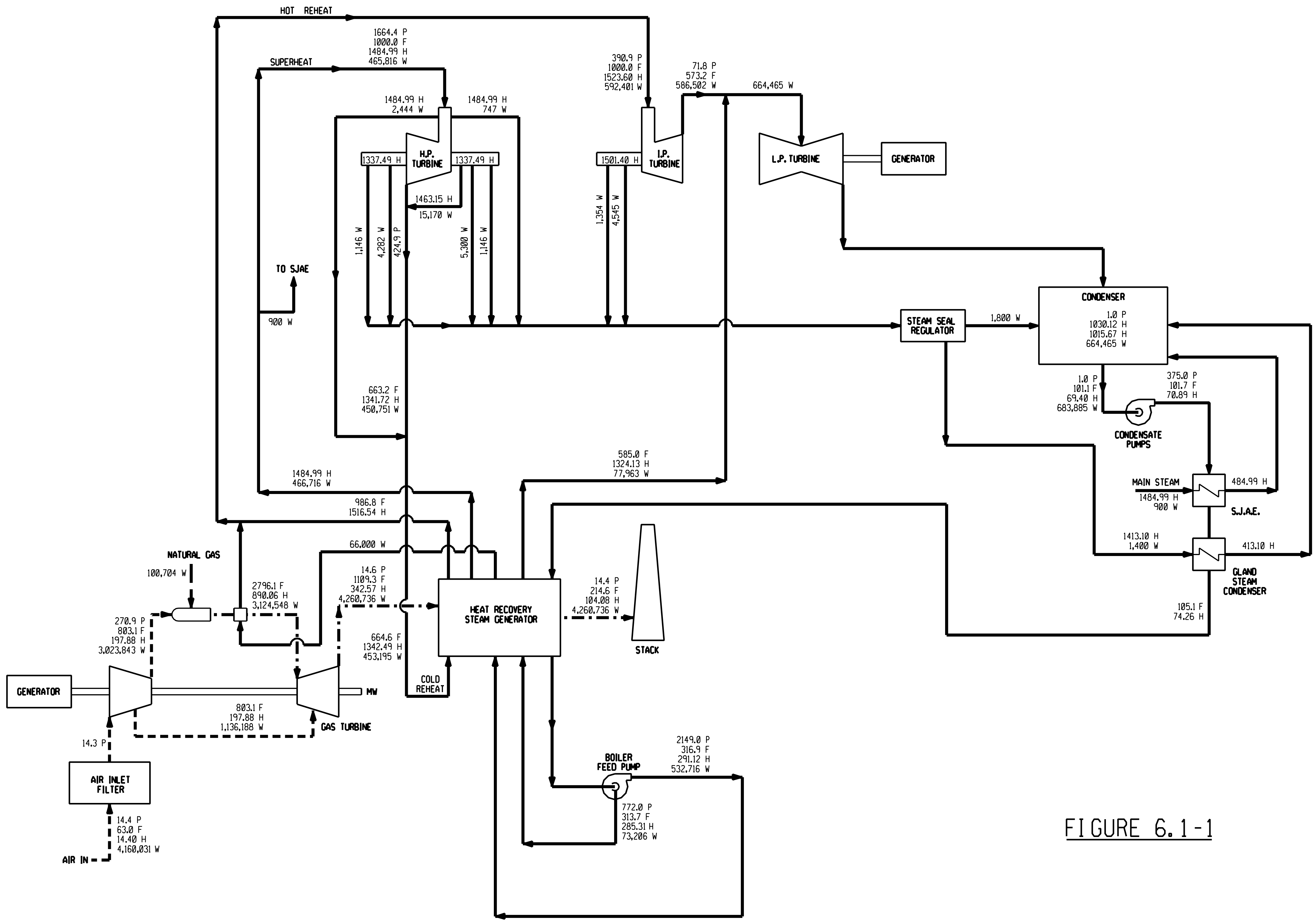

FIGURE 6.1-1

NOTES:

1. ENTHALPY REFERENCE POINT IS NATURAL STATE AT 32.018° F AND 0.08865 PSIA

DD

LEGEND

- - - - - -	AIR
— — —	FUEL GAS
— · — · —	COMBUSTION PRODUCTS
—×—×—	SOLIDS
———	WATER / STEAM
P	ABSOLUTE PRESSURE, PSIA
F	TEMPERATURE, °F
H	ENTHALPY, Btu/LB
W	TOTAL PLANT FLOW, LB/HR
MWe	POWER, MEGAWATTS ELECTRICAL

SYSTEM PERFORMANCE SUMMARY
(ONE GAS AND ONE STEAM TUBINE)

GAS T-G POWER :	229.430 MWe
STEAM T-G POWER :	110.979 MWe
GENERATOR LOSS (TOTAL):	6.438 MWe
AUXILIARY POWER (TOTAL):	7.830 MWe
NET PLANT POWER :	326.141 MWe
NET PLANT EFFICIENCY :	50.6 %
NET PLANT HEAT RATE :	6,743 Btu/kwh

REV | DATE | DESCRIPTION | DRAWN | CHECKED | LEAD DESIGNER | ENGINEER | LEAD DISCP ENGINEER | PROJ ENGR MANAGER | PROJECT MANAGER

STATUS OF DRAWING	DEFINITION
PRELIMINARY	REPRESENTS GENERAL DESIGN CONCEPTS BASED ON ASSUMPTIONS. REVIEWED NOT CHECKED.

CONSTRUCTION STATUS

DRAWN BY DATE
COK
CHECKED BY DATE
LEAD DESIGNER DATE
ENGINEER DATE
LEAD DISCIPLINE ENGR. DATE

ORIGINALLY PREPARED UNDER THE RESPONSIBLE SUPERVISION OF
PE: STATE:
LIC. NO.: DATE:
PROJECT ENGINEERING MANAGER
PROJECT MANAGER

PARSONS
PARSONS POWER GROUP INC.
READING / BOSTON / CHARLOTTE / CHATTANOOGA

CLIENT/PROJECT TITLE
CLEAN COAL TECHNOLOGY PROGRAM
NGCC PERFORMANCE
DEPARTMENT OF ENERGY TASK 22

PLANT HEAT AND MATERIAL BALANCE
100% RATED POWER

SCALE NONE
PARSON'S DWG. NO. MBAC-1-400-314-007
REV A

ARCH | HVAC | I & C | ELECT | MECH | CIVIL | STRUC

PPGI-FILE:
PPGI-DATE:

432006:40031407.GRA
432006:40031407.NOD

Reserved for reverse side of Figure 6.1-1 **(11x17)**

NOTES:
1. ENTHALPY REFERENCE POINT IS NATURAL STATE AT 32.018° F AND 0.08865 PSIA
2. IP BOILER IN HRSG GENERATES ADDITIONAL COLD REHEAT STEAM.

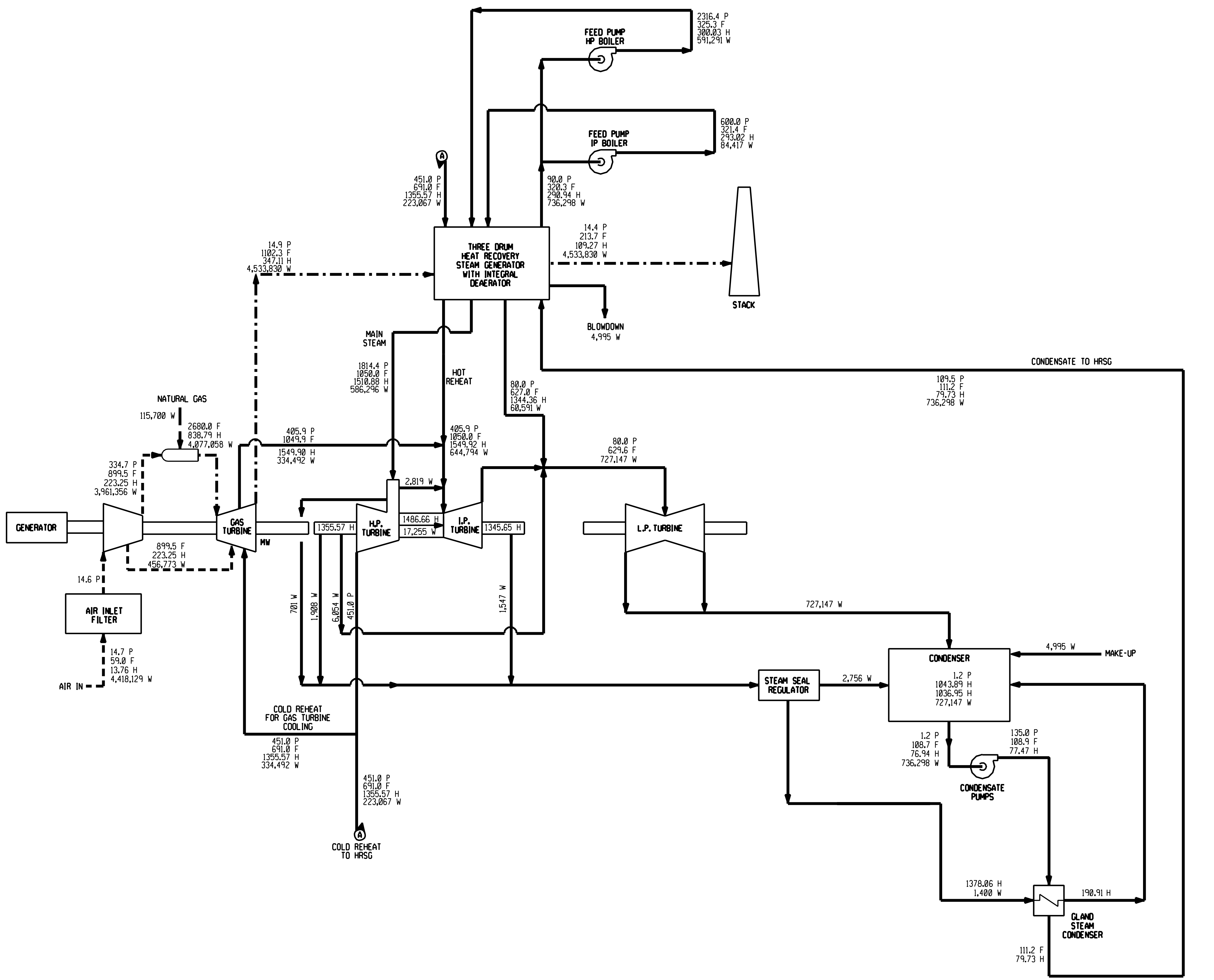

FIGURE 6.2-1

DD

LEGEND

	AIR / OXIDANT
	FUEL GAS
	COMBUSTION PRODUCTS
	SOLIDS
	WATER / STEAM
P	ABSOLUTE PRESSURE, PSIA
F	TEMPERATURE, °F
H	ENTHALPY, Btu/LB
W	TOTAL PLANT FLOW, LB/HR
MWe	POWER, MEGAWATTS ELECTRICAL

SYSTEM PERFORMANCE SUMMARY
(ONE GAS AND ONE STEAM TUBINE)

GAS T-G POWER :	280.000	MWe
STEAM T-G POWER :	129.479	MWe
GENERATOR LOSS (TOTAL):	6.142	MWe
TRANSFORMER LOSS (TOTAL):	1.370	MWe
AUXILIARY POWER (TOTAL):	6.940	MWe
NET PLANT POWER :	395.027	MWe
NET PLANT EFFICIENCY :	53.4	%
NET PLANT HEAT RATE :	6,396	Btu/kwh

J.S.WHITE 107HCC18 3/23/1998

REV | DATE | DESCRIPTION | DRAWN | CHECKED | LEAD DESIGNER | ENGINEER | LEAD DISCP ENGINEER | PROJ ENGR MANAGER | PROJECT MANAGER

STATUS OF DRAWING | DEFINITION | CONSTRUCTION STATUS
PRELIMINARY | REPRESENTS GENERAL DESIGN CONCEPTS BASED ON ASSUMPTIONS. REVIEWED NOT CHECKED.
LDE ___ DATE ___

CONCEPTUAL DESIGN
STUDY NOT FOR
CONSTRUCTION

DRAWN BY CLB DATE 3/22/98
CHECKED BY DATE
LEAD DESIGNER DATE
ENGINEER DATE
LEAD DISCIPLINE ENGR. DATE
ORIGINALLY PREPARED UNDER THE RESPONSIBLE SUPERVISION OF
PE: STATE:
LIC. NO.: DATE:
PROJECT ENGINEERING MANAGER
PROJECT MANAGER

PARSONS
PARSONS POWER GROUP INC.
READING / BOSTON / CHARLOTTE / CHATTANOOGA

CLIENT/PROJECT TITLE
CLEAN COAL TECHNOLOGY PROGRAM
NATURAL GAS COMBINED CYCLE
DEPARTMENT OF ENERGY TASK 22

PLANT HEAT AND MATERIAL BALANCE
100% RATED POWER
GENERAL ELECTRIC "H" ATS

SCALE NONE
PARSON'S DWG. NO. MBAC-1-400-314-009
REV A

ARCH | HVAC | I & C | ELECT | MECH | CIVIL | STRUC
PPGI-FILE:
PPGI-DATE:

416006:31898.GRA
416006:31898.DGN

Reserved for reverse side of Figure 6.1-2 **(11x17)**

The Rankine cycle for the plant utilizing the 501G machine is based on a 1650 psig/1000°F/ 1000°F single reheat configuration. The HP turbine receives 465,816 lb/h steam at 1665 psia and 1000°F from the HRSG. The cold reheat flow from the HP turbine to the reheater in the HRSG is 450,751 lb/h of steam at 425 psia and 663°F. The steam is combined with an additional 75,650 lb/h of steam generated in the IP drum of the HRSG; both streams combine and return to the HRSG to be reheated to 987°F. The steam returning from the transitions is mixed with the hot reheat steam for admission to the IP turbine section. The LP drum and superheater of the HRSG generate 77,963 lb/h of steam at 80 psia and 585°F for admission to the LP turbine at the cross-over.

The steam turbine is a single machine comprised of tandem HP, IP, and two-flow LP turbines driving one 3600 rpm hydrogen-cooled generator. The turbine is equipped with three sets of admission valves, one for each of the HP, IP, and LP turbines. The turbine exhausts to a single-pressure condenser operating at 2.0 inches Hga at the nominal 100 percent load design point. For the LP turbine, the last-stage bucket length is 23.0 inches, the pitch diameter is 65.5 inches, and the annulus area per end is 32.9 square feet.

The Rankine cycle for the plant utilizing the "H" machine is based on an 1800 psig/1050°F/ 1050°F single reheat configuration. The HP turbine receives 586,300 lb/h steam at 1815 psia and 1050°F from the HRSG. The cold reheat flow from the HP turbine to the reheater in the HRSG is 223,100 lb/h of steam at 450 psia and 691°F. An additional 334,500 lb/h of cold reheat is sent to the gas turbine for cooling the gas turbine. The hot reheat steam at 406 psia and 1050°F flows from the HRSG, joins with the steam from the gas turbine, and enters the IP section of the steam turbine. The LP drum and superheater of the HRSG generate 60,600 lb/h of steam at 80 psia and 627°F for admission to the LP turbine at the cross-over.

The steam turbine is a single machine comprised of tandem HP, IP, and two-flow LP turbines driving one 3600 rpm hydrogen-cooled generator. The turbine is equipped with three sets of admission valves, one for each of the HP, IP, and LP turbines. The turbine exhausts to a single-pressure condenser operating at 2.5 inches Hga at the nominal 100 percent load design point. For the LP turbine, the last-stage bucket length is 23.0 inches, the pitch diameter is 65.5 inches, and the annulus area per end is 32.9 square feet.

Condensate and feedwater heating is accomplished by heat recovery from the gas turbine exhaust in the HRSG. Condensate is defined as fluid pumped from the condenser hotwell to the deaerator inlet. Feedwater is defined as fluid pumped from the deaerator storage tank to the HRSG inlets.

In summary, the major features of the steam turbine cycles for these CT/HRSG plants include the following:

- Subcritical steam conditions and single reheat (1650 psig/1000°F/1000°F) / (1800 psig/ 1050°F/1050°F).
- Steam generated at three pressures in the HRSG, corresponding to main steam, reheat steam, and LP turbine (cross-over).
- Motor-driven boiler feed pumps.
- Turbine configuration based on one 3600 rpm tandem-compound, two-flow exhaust machine.
- A single deaerating heater, integral to the HRSG.
- Condensate and feedwater heating principally accomplished in the HRSG, recovering heat from the gas turbine exhaust.

6.1.3 Emissions Performance

The operation of the modern, state-of-the-art gas turbine fueled by natural gas, coupled to a HRSG, is projected to result in very low levels of SO_2 and NOx emissions. CO_2 emissions are reduced relative to those produced by burning coal, given the same power output and efficiency. Solid waste emissions are negligible.

Summaries of the plant emissions utilizing the 501G and "H" machines are presented in Table 6.1-3 and Table 6.1-4, respectively.

Table 6.1-3
AIRBORNE EMISSIONS - WESTINGHOUSE 501G COMBUSTION TURBINE/HRSG

	Values at Design Condition (65% and 85% Capacity Factor)			
	1b/10^6 Btu	**Tons/year 65%**	**Tons/year 85%**	**lb/MWh**
SO_2	Neg.	Neg.	Neg.	
NOx	< 0.028	188	246	0.202
Particulates	Neg.	Neg.	Neg.	
CO_2	118	738,502	965,734	796

Table 6.1-4
AIRBORNE EMISSIONS - GENERAL ELECTRIC "H" COMBUSTION TURBINE/HRSG

	Values at Design Condition (65% and 85% Capacity Factor)			
	1b/10^6 Btu	**Tons/year 65%**	**Tons/year 85%**	**lb/MWh**
SO_2	Neg.	Neg.	Neg.	
NOx	< 0.028	216	282	0.192
Particulates	Neg.	Neg.	Neg.	
CO_2	118	848,474	1,109,543	754

The elimination of SO_2 and particulate discharge is a consequence of using natural gas as the only fuel in this plant.

The low level of NOx production (<10 ppm) is achieved by the zoning and staging of combustion in the gas turbine combustors.

CO_2 emissions are low on an intensive basis (1b/10^6 Btu), and on a total basis (tons/year), due to the firing of natural gas.

6.1.4 <u>Combustion Turbine and Heat Recovery Steam Generator</u>

6.1.4.1 Combustion Turbine

The combustion turbine used for the first case is a Westinghouse Model 501G. This machine is an axial flow, single spool, constant speed unit with variable inlet guide vanes. A summary of the salient features of the machine is presented below:

- Inlet and Filter — Two-stage, renewable pad filters, preceded by a rain louver and screen
- Compressor — Axial flow, 17-stage, 19.2:1 pressure ratio
- Combustors — Can-annular, 16 cans, dry low-NOx type
- Turbine — Four stages (three cooled)
- Generator — Hydrogen-cooled, 20 kV, 60 Hz static exciter

The combustion turbine used for the second case is a General Electric Model “H.” This machine is an axial flow, single spool, constant speed unit with variable inlet guide vanes and four stages of variable stator vanes. A summary of the features of the machine is presented below:

- Inlet and Filter — Two-stage, renewable pad filters, preceded by a rain louver and screen
- Compressor — Axial flow, 18-stage, 23:1 pressure ratio
- Combustors — Can-annular, 12 cans, dry low-NOx type
- Turbine — Steam cooling - two stages; air cooling - one stage; no cooling - one stage
- Generator — Hydrogen-cooled, 20 kV, 60 Hz static exciter

6.1.4.2 Heat Recovery Steam Generator

The HRSG for both power plants is configured with HP, IP, and LP steam drums, and superheater, reheater, and economizer sections. The HP drum is supplied with feedwater by the HP boiler feed pump to generate HP steam, which passes to the superheater section for heating to 1000°F for the 501G plant and 1050°F for the H plant. The IP drum for the 501G plant is supplied with feedwater from an interstage bleed on the HP boiler feed pump. The IP drum for the “H” plant is supplied with feedwater from a separate boiler feed pump. The IP steam from the drum is mixed with cold reheat steam from the HP turbine exhaust; the combined flows pass to the reheat section for heating to 1000°F for the 510G plant and 1050°F for the “H” plant (final temperature after mixing with transition steam returning from the combustion turbine), for induction in the IP turbine. The LP drum provides steam to the integral deaerator, and also to the LP turbine.

Finally, the economizer sections heat condensate and feedwater (in separate tube bundles). The HRSG tube surface is typically comprised of bare surface and/or finned tubing or pipe material. The high-temperature portions are type P91 or P22 material; the low-temperature portions (< 750°F) will be carbon steel.

The HRSG exhausts directly to the new stack, which is fabricated from carbon steel plate materials and lined with Type 409 stainless steel.

6.1.5 CT/HRSG Support Systems (Balance of Plant)

6.1.5.1 Gas Lines

In this design, it is assumed that a natural gas main with adequate capacity is at the fenceline of the site and that a suitable right of way is available to install a branch line to the site. The gas pressure available in the main is assumed to be 350 psig for the purpose of this study. A gas line comprised of Schedule 40 carbon steel pipe, 16 inches nominal OD, is required to convey the gas to the site. The buried pipeline is coated and wrapped, and cathodically protected with a zinc ribbon-type sacrificial anode to protect the pipe from corrosion.

6.1.5.2 Gas Metering

A new gas metering station is located on the site, adjacent to the new combustion turbine. The meter may be of the rate-of-flow type, with input to the plant computer for summing and recording, or may be of the positive displacement type. In either case, a complete time-line record of gas consumption rates and cumulative consumption is provided.

6.1.5.3 Gas Booster Compressor

The 501G gas turbine requires a fuel gas pressure of 600 psig at the fuel inlet flange to the machine. The pressure delivered to the site, less losses in the branch main and in the metering station, is assumed to be about 300 psig. (This assumes an allowance of 50 psig for the pressure drop in the gas line to the site and in the metering station). Therefore, a fuel gas compressor is provided to boost the gas pressure to the required value. For the purposes of this study, a motor-driven screw type unit is provided, with the ability to deliver a nearly constant delivery pressure over a wide range of flow rates.

6.1.6 <u>Steam Cycle Balance of Plant</u>

6.1.6.1 Steam Turbine Generator and Auxiliaries

The steam turbine for both plants consists of an HP section, an IP section, and one double-flow LP section, all connected to the generator by a common shaft. The HP and IP sections are contained in a single span, opposed-flow casing, with the double-flow LP section in a separate casing. The LP turbine has a last-stage bucket length of 23 inches.

Main steam from the boiler passes through the stop valves and control valves and enters the turbine at 1650 psig/1000°F for the 501G plant and 1800 psig/1050°F for the "H" plant. The steam initially enters the turbine near the middle of the high-pressure span, flows through the turbine, and returns to the HRSG for reheating. The reheat steam flows through the reheat stop valves and intercept valves and enters the IP section at 375 psig/1000°F for the 501G plant and 395 psig/1050°F for the "H" plant. After passing through the IP section, the steam enters a cross-over pipe, which transports the steam to the LP section. A branch line equipped with combined stop/intercept valves conveys LP steam from the HRSG LP drum to a tie-in at the cross-over line. The steam divides into two paths and flows through the LP sections exhausting downward into the condenser.

Turbine bearings are lubricated by a closed-loop, water-cooled pressurized oil system. The oil is contained in a reservoir located below the turbine floor. During startup or unit trip the oil is pumped by an emergency oil pump mounted on the reservoir. When the turbine reaches

95 percent of synchronous speed, oil is pumped by the main pump mounted on the turbine shaft. The oil flows through water-cooled heat exchangers prior to entering the bearings. The oil then flows through the bearings and returns by gravity to the lube oil reservoir.

Turbine shafts are sealed against air in-leakage or steam blowout using a modern positive pressure variable clearance shaft sealing design arrangement connected to a low-pressure steam seal system. During startup, seal steam is provided from the main steam line. As the unit increases load, HP turbine gland leakage provides the seal steam. Pressure regulating valves control the gland header pressure and dump any excess steam to the condenser. A steam packing exhauster maintains a vacuum at the outer gland seals to prevent leakage of steam into the turbine room. Any steam collected is condensed in the packing exhauster and returned to the condensate system.

The generator is a hydrogen-cooled synchronous type, generating power at 23 kV. A static, transformer type exciter is provided.

The generator is cooled with a hydrogen gas recirculation system using fans mounted on the generator rotor shaft. The heat absorbed by the gas is removed as it passes over finned tube gas coolers mounted in the stator frame. Gas is prevented from escaping at the rotor shafts by a closed-loop oil seal system. The oil seal system consists of a storage tank, pumps, filters, and pressure controls, all skid-mounted.

The steam turbine generator is controlled by a triple-redundant microprocessor-based electro-hydraulic control system. The system provides digital control of the unit in accordance with programmed control algorithms, color CRT operator interfacing, and datalink interfaces to the balance-of-plant distributed control system (DCS), and incorporates on-line repair capability.

6.1.6.2 Condensate and Feedwater Systems

Condensate

The function of the condensate system is to pump condensate from the condenser hotwell to the deaerator, through the gland steam condenser; and the low-temperature economizer section in the HRSG.

Each system consists of one main condenser; two 50 percent capacity, motor-driven vertical condensate pumps; one gland steam condenser; and a low-temperature tube bundle in the HRSG.

Condensate is delivered to a common discharge header through two separate pump discharge lines, each with a check valve and a gate valve. A common minimum flow recirculation line discharging to the condenser is provided to maintain minimum flow requirements for the gland steam condenser and the condensate pumps.

Feedwater

The function of the feedwater system is to pump the various feedwater streams from the deaerator storage tank in the HRSG to the respective steam drums. Two 50 percent capacity motor-driven feed pumps are provided for HP service, and two 50 percent capacity motor-driven pumps are provided for IP service for the “H” plant. The HP pumps for the 501G plant are provided with an interstage takeoff to provide IP feedwater. Each pump is provided with inlet and outlet isolation valves, outlet check valves, and individual minimum flow recirculation lines discharging back to the deaerator storage tank. The recirculation flow is controlled by pneumatic flow control valves. In addition, the suctions of the boiler feed pumps are equipped with startup strainers, which are utilized during initial startup and following major outages or system maintenance.

6.1.6.3 Steam Systems

Main, Reheat, and Low-Pressure Steam

The function of the main steam system is to convey main steam from the HRSG superheater outlet to the HP turbine stop valves. The function of the reheat system is to convey steam from the HP turbine exhaust to the HRSG reheater and from the HRSG reheater outlet to the turbine reheat stop valves.

Main steam exits the HRSG superheater through a motor-operated stop/check valve and a motor-operated gate valve, and is routed to the HP turbine.

Cold reheat steam exits the HP turbine, and flows through a motor-operated isolation gate valve to the HRSG reheater. Hot reheat steam exits at the HRSG reheater through a motor-operated gate valve and is routed to the IP turbines.

6.1.6.4 Circulating Water System

The function of the circulating water system is to supply cooling water to condense the main turbine exhaust steam. The system consists of two 50 percent capacity vertical circulating water pumps, a mechanical draft evaporative cooling tower, and carbon steel cement-lined interconnecting piping. The condenser is a single pass, horizontal type with divided water boxes. There are two separate circulating water circuits in each box. One-half of the condenser can be removed from service for cleaning or plugging tubes. This can be done during normal operation at reduced load.

6.1.6.5 Major Steam Cycle Piping Required

A significant amount of high-temperature/high-pressure piping is required to connect the various components comprising the steam cycle. A summary of the required piping is presented in Table 6.1-5 for the 501G plant and Table 6.1-6 for the “H” plant.

6.1.7 Accessory Electric Plant

The accessory electric plant consists of all switchgear and control equipment, generator equipment, station service equipment, conduit and cable trays, wire, and cable. It also includes the main power transformer, all required foundations, and standby equipment.

6.1.8 Instrumentation and Control

An integrated plant-wide control and monitoring system (DCS) is provided. The DCS is a redundant microprocessor-based, functionally distributed system. The control room houses an array of multiple video monitor (CRT) and keyboard units. The CRT/keyboard units are the primary interface between the generating process and operations personnel. The DCS incorporates plant monitoring and control functions for all the major plant equipment. The DCS is designed to provide 99.5 percent availability.

Table 6.1-5
COMBUSTION TURBINE/HEAT RECOVERY STEAM GENERATOR (“G”)

Steam Cycle Piping Required

	Flow, lb/h	**Press., psia**	**Temp., °F**	**Mat'l**	**OD, in.**	**Twall, in.**
Condensate	685,000	375	100	A106 Gr. B	8	Sch. 40
IP Feedwater to HRSG	73,206	772	315	A106 Gr. B	4	Sch. 40
HP Feedwater to HRSG	532,700	2149	317	A106 Gr. B	8	Sch. 160
Main Steam to ST	466,000	1664	1000	A335 Gr. P22	8	1.25
Cold Reheat to HRSG	451,000	410	665	A106 Gr. B	16	Sch. 40
Hot Reheat to ST	595,000	390	1000	A335 Gr. P22	18	Sch. 40
LP Steam from HRSG to ST	78,000	72	585	A106 Gr. B	12	Sch. 40
Transition Cooling Steam to GT	66,000	600	570	A106 Gr. B	6	Sch. 40
Transition Cooling Steam from GT	66,000	390	1110	A 335 Gr. P22	8	Sch. 120

Table 6.1-6
COMBUSTION TURBINE/HEAT RECOVERY STEAM GENERATOR (“H”)

Steam Cycle Piping Required

	Flow, lb/h	**Press., psia**	**Temp., °F**	**Mat'l**	**OD, in.**	**Twall, in.**
Condensate	736,300	135	110	A106 Gr. B	8	Sch. 40
IP Feedwater to HRSG	84,400	600	320	A106 Gr. B	4	Sch. 40
HP Feedwater to HRSG	591,300	2320	325	A106 Gr. B	8	Sch. 160
Main Steam to ST	586,300	1815	1050	A335 Gr. P22	10	1.25
Cold Reheat to HRSG	223,100	451	690	A106 Gr. B	10	Sch. 40
Hot Reheat to ST	644,790	400	1050	A335 Gr. P22	18	Sch. 40
LP Steam to ST	61,000	80	630	A106 Gr. B	12	Sch. 40
Cold Reheat Cooling Steam to GT	334,490	451	690	A106 Gr. B	12	Sch. 40
Transition Cooling Steam from GT	334,492	405	1050	A 335 Gr. P22	14	Sch. 120

Note: Flow conditions in the above tables are nominal, rounded values.

The plant equipment and the DCS are designed for automatic response to load changes from minimum load to 100 percent. Startup and shutdown routines are implemented as supervised manual with operator selection of modular automation routines available.

6.1.9 Site, Structures, and Systems Integration

The development of the reference plant site to incorporate the new structures required for this technology is based on the assumption of a flat site. The gas turbine and its ancillary equipment are located in a turbine building. A HRSG and stack are north of the gas turbine, with the steam turbine and its generator in a separate building continuing the development to the north. Service and administration buildings are located at the north end of the steam turbine building.

The arrangement described above provides good alignment and positioning for major interfaces, as well as relatively short steam, feedwater, and fuel gas pipelines, and allows good access for vehicular traffic. Transmission line access from the gas turbine step-up transformer to the switchyard is also maintained at short distances.

The air and gas path is developed in a short and direct manner, with ambient air entering an inlet filter/silencer located east of the gas turbine. Air from the compressor discharge flows through the can-annular combustor where it supports combustion of the natural gas. The hot combustion product gases are expanded through the turbine section, and pass through a triple-pressure HRSG and then to a 213-foot stack. The height of the stack is established by application of a good engineering practice rule from 40 CFR 51.00.

6.1.10 Equipment List 301G Machine Plant - Major

ACCOUNT 1 COAL AND SORBENT HANDLING

ACCOUNT 1A COAL RECEIVING AND HANDLING

Not Applicable

ACCOUNT 1B LIMESTONE HANDLING AND PREPARATION SYSTEM

Not Applicable

ACCOUNT 2 FUEL AND SORBENT PREPARATION AND FEED

ACCOUNT 2A FUEL PREPARATION AND FUEL INJECTION

Equipment No.	Description	Type	Design Condition	Qty
1	Gas Pipeline	Underground, carbon steel, coated and wrapped, cathodic protection	36,800 scfm, 350 psig 16 in. OD, Sch. 40	10 miles
2	Gas Metering Station		36,800 scfm	1
3	Gas Booster Compressor	Screw type, motor driven	36,800 scfm, inlet P: 300 psig disch P: 625 psig	2

ACCOUNT 2B SORBENT PREPARATION AND FEED

Not Applicable

ACCOUNT 3 FEEDWATER AND MISCELLANEOUS SYSTEMS AND EQUIPMENT

ACCOUNT 3A CONDENSATE AND FEEDWATER SYSTEM

Equipment No.	Description	Type	Design Condition	Qty
1	Cond. Storage Tank	Vertical, cyl., outdoor	50,000 gal	2
2	Condensate Pumps	Vert. canned	700 gpm @ 900 ft	2
3	HP Feed Pumps	Horizontal split case Multi-staged, centr. with interstage bleed for IP feedwater	530 gpm @ 5,540 ft, 80 gpm @ 1,950 ft	2

ACCOUNT 3B MISCELLANEOUS EQUIPMENT

Equipment No.	Description	Type	Design Condition	Qty
2	Fuel Oil Storage Tank	Vertical, cylindrical	20,000 gal	2
3	Fuel Oil Unloading Pump	Gear	50 psig, 100 gpm	1
4	Fuel Oil Supply Pump	Gear	150 psig, 5 gpm	2
5	Service Air Compressors	Recip., single stage, double-acting, horiz.	100 psig, 450 cfm	2
6	Inst. Air Dryers	Duplex, regenerative	450 cfm	1
7	Service Water Pumps	Horiz. centrifugal, double suction	200 ft, 700 gpm	2
8	Closed Cycle Cooling Heat Exchanger	Plate and frame	50% cap. each	2
9	Closed Cycle Cooling Water Pumps	Horizontal, centrifugal	70 ft, 700 gpm	2
11	Fire Service Booster Pump	Two-stage horiz. cent.	250 ft, 700 gpm	1
12	Engine-Driven Fire Pump	Vert. turbine, diesel engine	350 ft, 1000 gpm	1
13	Raw Water	SS, single suction	60 ft, 100 gpm	2
14	Filtered Water Pumps	SS, single suction	160 ft, 120 gpm	2
15	Filtered Water Tank	Vertical, cylindrical	15,000 gal	1
16	Makeup Demineralizer	Anion, cation, and mixed bed	150 gpm	2
17	Liquid Waste Treatment System		10 years, 25-hour storm	1

ACCOUNT 4 PFBC BOILER AND ACCESSORIES

Not Required

ACCOUNT 5 FLUE GAS CLEANUP

Not Required

ACCOUNT 6 COMBUSTION TURBINE AND AUXILIARIES

Equipment No.	Description	Type	Design Condition	Qty
1	230 MWe Gas Turbine Generator	Axial flow single spool based on W501G	1200 lb/sec airflow 2580°F rotor inlet temp. 19.2:1 pressure ratio	1
2	Enclosure	Sound attenuating	85 db at 3 ft outside the enclosure	1
3	Air Inlet Filter/Silencer	Two-stage	1200 lb/sec airflow 3.0 in. H_2O pressure drop, dirty	1
4	Starting Package	Electric motor, torque converter drive, turning gear	2,500 hp, time from turning gear to full load ~30 minutes	1
5	Air to Air Cooler			1
6	Mechanical Package	CS oil reservoir and pumps dual vertical cartridge filters air compressor		1
7	Oil Cooler	Air-cooled, fin fan		1
8	Electrical Control Package	Distributed control system	1 sec. update time/ 8 MHz clock speed	1
9	Generator Glycol Cooler	Air-cooled, fin fan		1
10	Compressor Wash Skid			1
11	Fire Protection Package	Halon		1

ACCOUNT 7 WASTE HEAT BOILER, DUCTING, AND STACK

Equipment No.	Description	Type	Design Condition Drums	Qty
1	Heat Recovery Steam Generator	Drum, triple pressure, with economizer section and integral deaerator	HP-2100 psig/315°F 467,000 lb/h, superheat to 1000°F	1
			IP-770 psig/313°F 75,650 lb/h, superheat to 987°F	
			LP-65 psig/312°F 78,000 lb/h, superheat to 585°F	
2	Stack	Carbon steel plate, lined with type 409 stainless steel	213 ft high x 28 ft dia.	1

ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

Equipment No.	Description	Type	Design Condition	Qty
1	110 MW Turbine Generator	TC2F23, triple admissions	1650 psig 1000°F/1000°F	1
2	Bearing Lube Oil Coolers	Plate and frame		2
3	Bearing Lube Oil Conditioner	Pressure filter closed loop		1
4	Control System	Digital electro-hydraulic	1600 psig	1
5	Generator Coolers	Plate and frame		2
6	Hydrogen Seal Oil System	Closed loop		1
7	Surface Condenser	Single pass, divided waterbox	680,000 lb/h steam @ 2.0 in. Hga with 74°F water, 20°F temp. rise	1
8	Condenser Vacuum Pumps	Rotary, water sealed	2000/20 scfm (hogging/holding)	2

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition (per each)	Qty
1	Circ. W. Pumps	Vert. wet pit	34,000 gpm @ 80 ft	2
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	52°F WB/74°F CWT/ 94° HWT	1

ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

Not Applicable

6.1.11 Equipment List "H" Machine Plant - Major

ACCOUNT 1 COAL AND SORBENT HANDLING

ACCOUNT 1A COAL RECEIVING AND HANDLING

Not Applicable

ACCOUNT 1B LIMESTONE HANDLING AND PREPARATION SYSTEM

Not Applicable

ACCOUNT 2 FUEL AND SORBENT PREPARATION AND FEED

ACCOUNT 2A FUEL PREPARATION AND FUEL INJECTION

Equipment No.	Description	Type	Design Condition	Qty
1	Gas Pipeline	Underground, carbon steel, coated and wrapped, cathodic protection	105,829 lb/h, 350 psig 18 in. OD, Sch. 40	10 miles
2	Gas Metering Station		105,829 lb/h	1
3	Gas Booster Compressor	Screw type, motor driven	105,829 scfm, inlet P: 300 psig disch P: 625 psig	2

ACCOUNT 2B SORBENT PREPARATION AND FEED

Not Applicable

ACCOUNT 3 FEEDWATER AND MISCELLANEOUS SYSTEMS AND EQUIPMENT

ACCOUNT 3A CONDENSATE AND FEEDWATER SYSTEM

Equipment No.	Description	Type	Design Condition	Qty
1	Cond. Storage Tank	Vertical, cyl., outdoor	50,000 gal	2
2	Condensate Pumps	Vert. canned	750 gpm @ 310 ft	2
3	IP Feed Pumps	Horizontal split case Multi-staged, centr. with interstage bleed for IP feedwater	84 gpm @ 1,177 ft	2
4	HP Feed Pumps	Horizontal split case Multi-staged	600 gpm @ 5,100 ft	2

ACCOUNT 3B MISCELLANEOUS EQUIPMENT

Same as 501G plant

ACCOUNT 4 PFBC BOILER AND ACCESSORIES

Not Required

ACCOUNT 5 FLUE GAS CLEANUP

Not Required

ACCOUNT 6 COMBUSTION TURBINE AND AUXILIARIES

Equipment No.	Description	Type	Design Condition	Qty
1	280 MWe Gas Turbine Generator	Axial flow single spool based on "H"	1510 lb/sec airflow 2600°F rotor inlet temp. 23:1 pressure ratio	1
2	Enclosure	Sound attenuating	85 db at 3 ft outside the enclosure	1
3	Air Inlet Filter/Silencer	Two-stage	1510 lb/sec airflow 3.0 in. H_2O pressure drop, dirty	1
4	Starting Package	Electric motor, torque converter drive, turning gear	2,500 hp, time from turning gear to full load ~30 minutes	1
5	Mechanical Package	CS oil reservoir and pumps dual vertical cartridge filters air compressor		1
6	Oil Cooler	Air-cooled, fin fan		1
7	Electrical Control Package	Distributed control system	1 sec. update time/ 8 MHz clock speed	1
8	Generator Glycol Cooler	Air-cooled, fin fan		1
9	Compressor Wash Skid			1
10	Fire Protection Package	Halon		1

ACCOUNT 7 WASTE HEAT BOILER, DUCTING, AND STACK

Equipment No.	Description	Type	Design Condition Drums	Qty
1	Heat Recovery Steam Generator	Drum, triple pressure, with economizer section and integral deaerator	HP-2300 psig/325°F 591,300 lb/h, superheat to 1050°F IP-585 psig/321°F 84,400 lb/h, superheat to 927°F	1
2	Stack	Carbon steel plate, lined with type 409 stainless steel	213 ft high x 28 ft dia.	1

ACCOUNT 8 STEAM TURBINE GENERATOR AND AUXILIARIES

Equipment No.	Description	Type	Design Condition	Qty
1	130 MW Turbine Generator	TC2F23, triple admissions	1800 psig 1000°F/1000°F	1
2	Bearing Lube Oil Coolers	Plate and frame		2
3	Bearing Lube Oil Conditioner	Pressure filter closed loop		1
4	Control System	Digital electro-hydraulic	1600 psig	1
5	Generator Coolers	Plate and frame		2
6	Hydrogen Seal Oil System	Closed loop		1
7	Surface Condenser	Single pass, divided waterbox	727,000 lb/h steam @ 2.0 in. Hga with 74°F water, 20°F temp. rise	1
8	Condenser Vacuum Pumps	Rotary, water sealed	2000/20 scfm (hogging/holding)	2

ACCOUNT 9 COOLING WATER SYSTEM

Equipment No.	Description	Type	Design Condition (per each)	Qty
1	Circ. W. Pumps	Vert. wet pit	37,000 gpm @ 80 ft	2
2	Cooling Tower	Evaporative, mechanical draft, multi-cell	52°F WB/74°F CWT/ 94° HWT	1

ACCOUNT 10 ASH/SPENT SORBENT RECOVERY AND HANDLING

Not Applicable

6.1.12 Conceptual Capital Cost Estimate Summary

The summary of the conceptual capital cost estimate for the NGCC plant is shown in Table 6.1-7 and Table 6.1-8. The estimate summarizes the detail estimate values that were developed consistent with Section 9, “Capital and Production Cost and Economic Analysis.” The detail estimate results are contained in Appendix E.

Examination of the values in the table reveal several relationships that are subsequently addressed. The relationship of the equipment cost to the direct labor cost varies for each account. This variation is due to many factors including the level of fabrication performed prior to delivery to the site, the amount of bulk materials represented in the equipment or material cost column, and the cost basis for the specific equipment (degree of field fabrication required for items too large to ship to the site in one or several major pieces). Also note that the total plant cost ($/kW) values are all determined on the basis of the total plant net output. This will be more evident as other technologies are compared. One significant change compared to the PC technologies is that the power is generated by multiple sources. As a result, the steam turbine portions have a good economy of scale, but the combustion turbine and technology do not.

Table 6.1-7

Client: DEPARTMENT OF ENERGY - Task 36
Project: Market Based Advanced Coal Power Systems

Report Date: 16-Dec-98
05:28 PM

TOTAL PLANT COST SUMMARY

Case: Natural Gas Combined Cycle-"G"
Plant Size: 326.1 MW,net **Estimate Type:** Conceptual **Cost Base (Jan)** 1998 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING											
2	COAL & SORBENT PREP & FEED											
3	FEEDWATER & MISC. BOP SYSTEMS	4,835	2,213	3,785	265		**$11,097**	888		2,905	**$14,891**	46
4	GASIFIER & ACCESSORIES											
4.1	Gasifier & Auxiliaries											
4.2	High Temperature Cooling											
4.3	Recycle Gas System											
4.4-4.9	Other Gasification Equipment											
	SUBTOTAL 4											
5	HOT GAS CLEANUP & PIPING											
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	39,817		2,820	197		**$42,834**	3,427		4,626	**$50,887**	156
6.2-6.9	Combustion Turbine Accessories		136	157	11		**$305**	24		99	**$428**	1
	SUBTOTAL 6	*39,817*	*136*	*2,977*	*208*		***$43,139***	*3,451*		*4,725*	***$51,315***	*157*
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	12,541		1,803	126		**$14,470**	1,158		1,563	**$17,190**	53
7.2-7.9	HRSG Accessories, Ductwork and Stack	1,750	651	1,236	87		**$3,724**	298		558	**$4,580**	14
	SUBTOTAL 7	*14,291*	*651*	*3,039*	*213*		***$18,194***	*1,456*		*2,121*	***$21,770***	*67*
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	9,644		1,589	111		**$11,345**	908		1,225	**$13,477**	41
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	4,365	133	2,394	168		**$7,060**	565		1,313	**$8,937**	27
	SUBTOTAL 8	*14,010*	*133*	*3,983*	*279*		***$18,404***	*1,472*		*2,538*	***$22,415***	*69*
9	COOLING WATER SYSTEM	3,113	1,728	2,934	205		**$7,980**	638		1,549	**$10,168**	31
10	ASH/SPENT SORBENT HANDLING SYS											
11	ACCESSORY ELECTRIC PLANT	7,525	1,799	4,793	336		**$14,454**	1,156		2,530	**$18,140**	56
12	INSTRUMENTATION & CONTROL	2,668	1,367	4,760	333		**$9,128**	730		1,644	**$11,501**	35
13	IMPROVEMENTS TO SITE	1,674	962	3,352	235		**$6,224**	498		2,016	**$8,738**	27
14	BUILDINGS & STRUCTURES		3,731	4,841	339		**$8,911**	713		2,406	**$12,030**	37
	TOTAL COST	**$87,934**	**$12,721**	**$34,464**	**$2,412**		**$137,531**	**$11,002**		**$22,434**	**$170,968**	**524**

Table 6.1-8

Client: DEPARTMENT OF ENERGY - Task 36 **Report Date:** 17-Dec-98 05:44 PM
Project: Market Based Advanced Coal Power Systems

TOTAL PLANT COST SUMMARY

Case: Natural Gas Combined Cycle-"H"
Plant Size: 395.0 MW,net **Estimate Type:** Conceptual **Cost Base (Jan)** 1998 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING											
2	COAL & SORBENT PREP & FEED											
3	FEEDWATER & MISC. BOP SYSTEMS	5,172	2,381	4,027	282		**$11,862**	949		3,110	**$15,922**	40
4	GASIFIER & ACCESSORIES											
4.1	Gasifier & Auxiliaries											
4.2	High Temperature Cooling											
4.3	Recycle Gas System											
4.4-4.9	Other Gasification Equipment											
	SUBTOTAL 4											
5	HOT GAS CLEANUP & PIPING											
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	41,448		3,306	231		**$44,986**	3,599		4,859	**$53,444**	135
6.2-6.9	Combustion Turbine Accessories		148	170	12		**$330**	26		107	**$463**	1
	SUBTOTAL 6	*41,448*	*148*	*3,477*	*243*		***$45,316***	*3,625*		*4,965*	***$53,907***	*136*
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	13,414		1,928	135		**$15,477**	1,238		1,672	**$18,387**	47
7.2-7.9	HRSG Accessories, Ductwork and Stack	1,758	654	1,241	87		**$3,740**	299		560	**$4,600**	12
	SUBTOTAL 7	*15,172*	*654*	*3,169*	*222*		***$19,217***	*1,537*		*2,232*	***$22,986***	*58*
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	9,984		1,828	128		**$11,940**	955		1,289	**$14,184**	36
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	4,883	149	2,678	187		**$7,897**	632		1,469	**$9,997**	25
	SUBTOTAL 8	*14,867*	*149*	*4,506*	*315*		***$19,837***	*1,587*		*2,758*	***$24,182***	*61*
9	COOLING WATER SYSTEM	3,476	1,935	3,275	229		**$8,916**	713		1,731	**$11,360**	29
10	ASH/SPENT SORBENT HANDLING SYS											
11	ACCESSORY ELECTRIC PLANT	8,105	1,811	4,912	344		**$15,171**	1,214		2,649	**$19,034**	48
12	INSTRUMENTATION & CONTROL	2,867	1,469	5,115	358		**$9,810**	785		1,766	**$12,361**	31
13	IMPROVEMENTS TO SITE	1,831	1,053	3,667	257		**$6,807**	545		2,206	**$9,557**	24
14	BUILDINGS & STRUCTURES		4,001	5,204	364		**$9,569**	766		2,584	**$12,918**	33
	TOTAL COST	**$92,938**	**$13,601**	**$37,352**	**$2,615**		**$146,506**	**$11,720**		**$24,001**	**$182,227**	**461**

This page left blank intentionally